Wind velocity and direction aloft were obtained by means of pilot balloons, and all stations were supplied with equipment for making pilot-balloon ascents. The ballons were inflated to give a rise of 400 or 500 feet per minute, according to the size of balloon used. This rate of rise facilitated rapid calculation; and by the single-theodolite method, with the theodolite near the office, two men could take the data, make the horizontal projection of the balloon path, and within one minute from the time the balloon was lost, complete the tabulation of the wind velocity and direction for all levels reached. A check on the rate of rise was sometimes made by the two-theodolite method. It showed that a balloon with the 500-foot rate varies from 425 to 600 feet per minute, though usually it is not very far from 500 feet. Such a departure from the assumed rate would cause a large percentage of error, but for velocities most suitable for flying it would mean an error of only a few miles an hour. In making night ascents a small candle lantern was tied to the balloon.[1]

Data from the pilot-balloon ascents as well as from surface instruments were used in plotting dead-reckoning courses for seaplane patrol. The wind direction was given in degrees to facilitate computing the drift angle, as most patrols consisted of many courses. Surface-wind data were obtained from the Dines anemograph, which gives instantaneous wind direction and velocity. In case the outlook was unfavorable for a dawn patrol upon the advice of the station meteorological officer the planes were not taken out of the hangars; and if dangerous winds were expected when planes were out it was the duty of the meteorological officer to see that they were recalled.

The type of meteorological hut used in British and American air stations is shown in the accompanying photograph (fig. 2).

[1] See pp. 221, above.

BLUE HILL METHODS OF "PILOT BALLOONING."[1]

By IVOR MALL, Ensign, U. S. N. R. F.

[Dated: Blue Hill Observatory, Readville, Mass., March, 1919.]

Pilot balloons are used to determine wind velocity and direction at various altitudes. To accomplish this, the balloon is released and its successive positions at intervals of one minute are observed through a theodolite. The vertical, or altitude, angle, and the azimuth, or horizontal, angle are noted at each of these minute intervals. From these data, and an assumed constant rate of ascent, the velocities and directions at different levels are calculated.

The solution of the data makes use of simple geometric and trigonometric principles. In order to make the operation more vivid, it is well to concentrate the attention on the procedure and try to visualize what happens when the balloon is released, and then to determine the value of the recorded data.

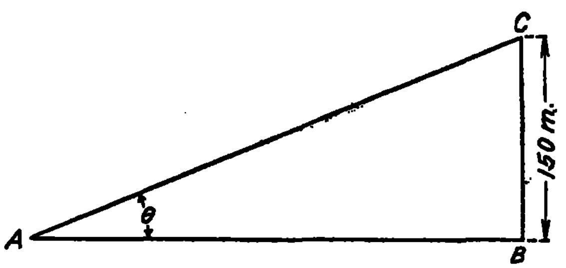

FIG. 1.—A represents the point at which we are standing and what we shall call the base; C is the position of the balloon; B is a point projected vertically below C; θ is the recorded vertical angle.

Let us stand with our backs to the wind and with a properly inflated balloon at hand. We will assume that the balloon when released will have a constant rate of ascent (150 m./min.). We release the balloon and it starts to rise and is carried out and away from us by the force of the wind. At the end of one minute we observe its position with the theodolite. According to our assumption its height is 150 meters. We record the vertical angle. This is represented in figure 1. AB represents the horizontal distance with respect to the earth that the balloon has traveled in one minute. If we divide the distance AB by 60, we obtain the wind velocity in meters per second (m./s.).

To find AB we have the following trigonometric relation:

$$BC \cot \theta = AB.$$

With AB determined we convert it into terms of velocity as explained above.

The above description shows what has happened in the vertical plane. If the wind direction were constant, this reasoning would be sufficient, but as this is not true another condition is introduced the explanation of which follows.

Let us go back to the point where we released the balloon. We observe its movement at minute intervals as it moves away. After a few minutes we notice that the balloon is being deflected to our right. This would lead us to the conclusion that the wind at the higher levels is from our left rear. In other words, the wind direction is changing as we go aloft. This variation is measured by noting the change of the horizontal angle, or azimuth. A movement takes place laterally with respect to the horizontal plane, which is represented in figure 2. The line AO represents the true balloon travel, hence its velocity. As the balloon has been blown from A to O, it

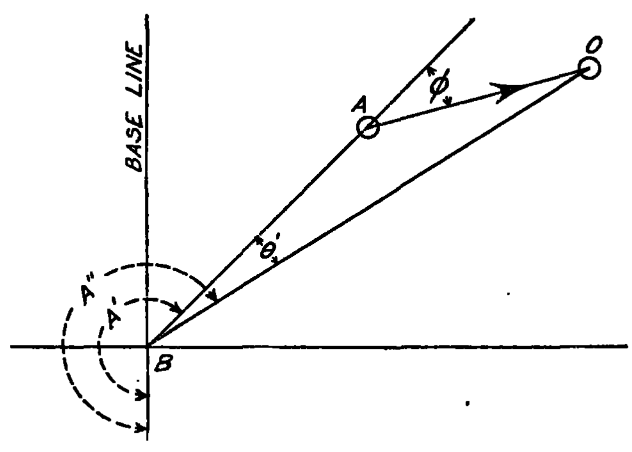

FIG. 2.—B is the base; A and O are successive positions of the balloon at any interval; A'=azimuth of position A; A''=azimuth of position O; θ'=difference in azimuth; φ=angle between line of sight of nearest position of balloon and the line of travel of the balloon.

[1] Published by permission of the Secretary of the Navy.

also shows the direction of the wind as indicated by the arrow. It is now necessary to obtain the direction of AO with respect to the "base line."

If the line of sight BA is extended it forms with AO the definite angle ϕ. It is obvious that if ϕ is added to A′ the true direction of AO with respect to the base line is obtained.

A complete observation will necessitate dealing with motion in both the vertical and horizontal planes. The "Davy Calculator" (fig. 3), combines polar and rectangular coordinates, and thus makes it possible to represent both planes on the same surface. A reference to the "Davy Calculator," figure 3, will show that an application of rectangular coordinates gives a graphical solution of the relation, BC $\cot\theta = AB$. The polar

To apply to "Calculator" (fig. 3).

1. Read up on the left-hand scale (vertical distance in meters) to 150. Follow this over to where it intersects the altitude angle 31.8°. Project this intersection vertically downward to the bottom scale, and read horizontal distance and velocity directly. (Dist. = 220 m.; vel. = 4 m. p. s.) The direction from which the wind is coming is the same as the azimuth.

2. Read up on the left-hand scale to 300 meters. Follow this line over to where it intersects the vertical angle 35.6°. Project this intersection vertically downward to the bottom scale. Reference is now made to the accompanying figure 4.

X is the point just established on the bottom scale. With BX as a radius and B as a center, describe an arc

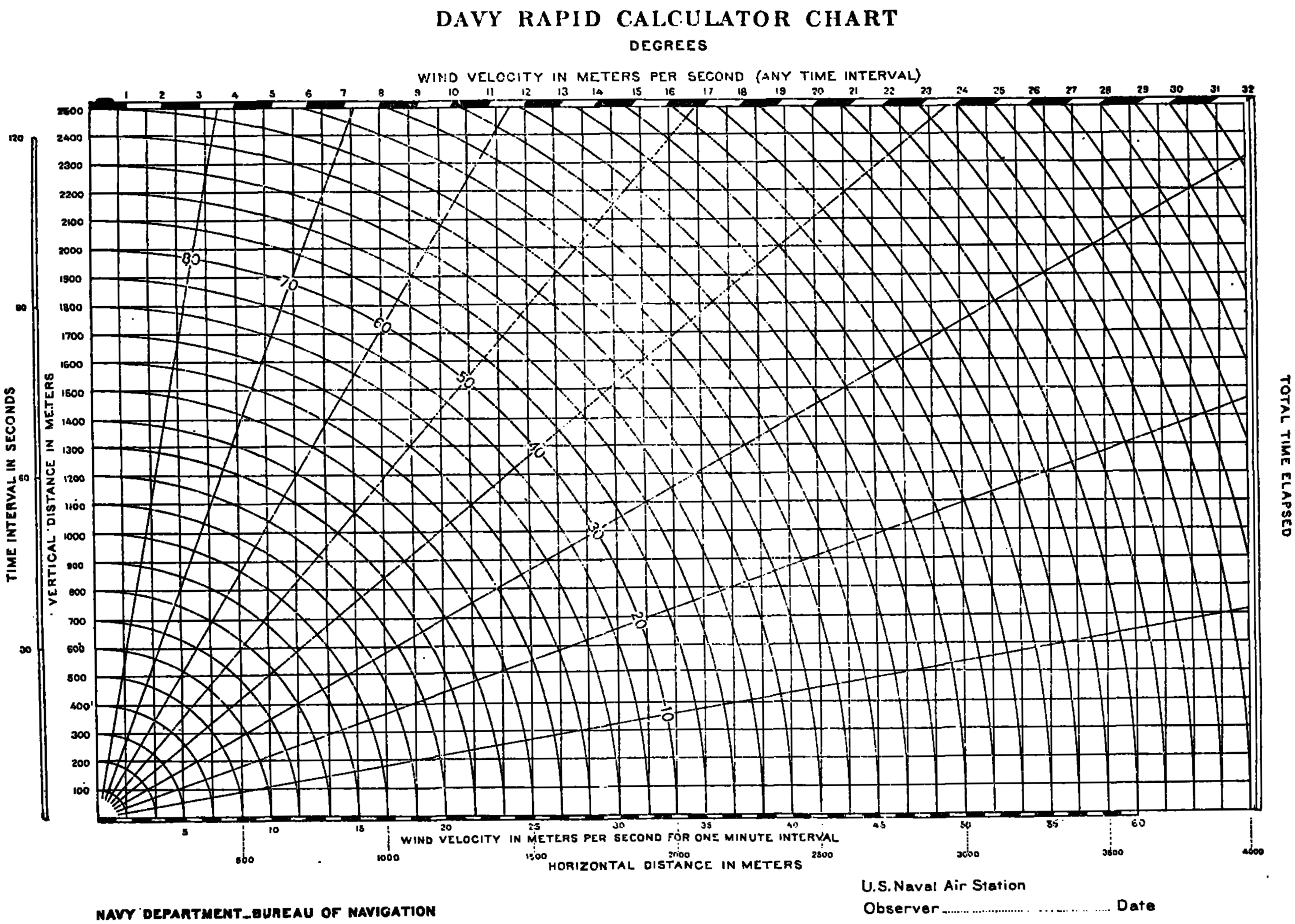

FIG. 3.

coordinates form a graphical solution of a change in azimuth. To show the use of the "Calculator," the calculation for the following data will be followed through.

Time.	Height.	Altitude.	Azimuth.	Velocity.	Direction.
	Meters.	°	°	*M./s.*	°
2:55					
2:56	150	31.8	90.5	4.0	90.5
2:57	300	35.6	93.2	3.0	97.5
2:58	450	34.6	95.2	3.7	100.7
2:59	600	33.1	101.0	4.5	115.2
3:00	750	31.4	107.0	4.5	124.0

of a circle equal to the difference in the azimuths 1 and 2 (2.7°) and establish the point Y. Project vertically downward from Y and establish the point Z on the bottom scale. The velocity for the second period of observation is equal to (BZ − BW) = WZ = 3.0.

If the angle YWZ (7.0°) be added to the azimuth of the previous observation, we obtain the direction of WY, or (90.5 + 7.0) = 97.5°.

Follow through identical steps for all observations.

The following points should be noted:

1. If the difference in azimuth if 5° or less it is not necessary to swing up through this angle to obtain the

velocity, as the second point when projected down will nearly coincide with the first; but it is necessary to swing this point up to obtain the change in direction of the wind.

2. The angle ϕ will not always be added to the previous azimuth. A set of four rules is furnished with the "Calculator" which are to be applied in determining the wind direction.

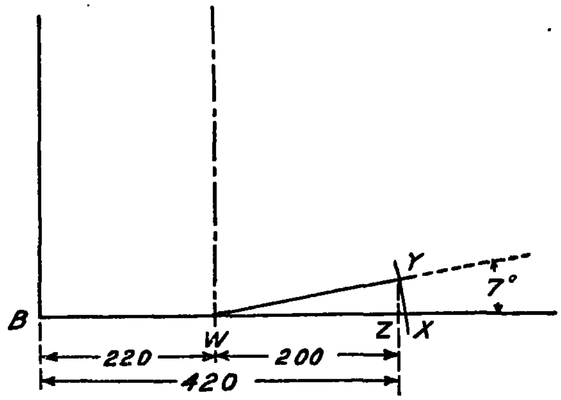

FIG. 4.

THE "TWITCHELL" METHOD.

This method applies a mechanical device to the "Calculator" which makes the manipulation much easier, simpler, and quicker to follow through. A graduated celluloid scale is pivoted at the origin of the calculator as shown in figure 3.

The point O is pivoted at the origin of the "Calculator." the scale OBX is graduated in the proper relation to the scale of the calculator, so that it reads directly in m. p. s.

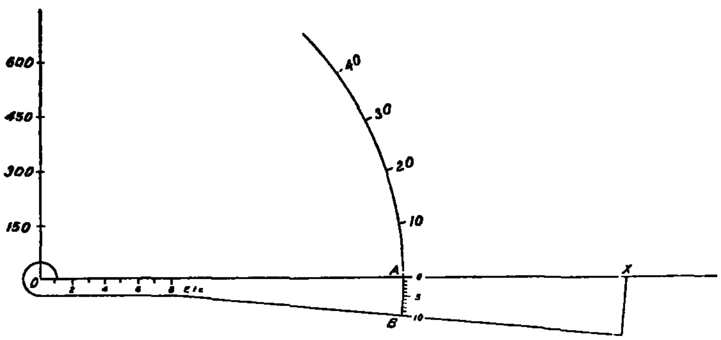

FIG. 5—The "Twitchell" method.

At a radius of about 20 cm. from O there is a modified vernier scale, AB. The arc AB is made to equal exactly 10° of a circle of that particular radius. On the calculator it is necessary to have only 10° divisions as the scale allows for any fraction between these divisions.

The use of the rule is as follows:

We will assume the same data as before.

1. Read up the left-hand distance scale to 150 meters. Set the lever so that the ruled edge lies on the 31.8° line. Read over on the 150 meter line until it intersects this edge. Follow this point vertically downward to the scale below. Move the lever down so that the ruled edge coincides with the bottom of the chart and read the velocity from the lever in m. p. s.

2. Read up the left-hand distance scale to 300 meters. Set the lever to read the vertical angle 35.6°. Find the intersection with the 300-meter line and project the point vertically downward to the bottom scale. By means of the lever establish the point Y as in figure 3. By means of an auxiliary scale measure the horizontal and vertical distances of this point from the point W, figure 3, and lay them off from the origin. They determine a point which in turn determines ϕ. Let the lever measure this angle (7.0°). Add this to the previous azimuth and obtain the wind direction $(90.5+7.0)=97.5°$. The distance WZ gives the wind velocity.

The steps are the same for succeeding operations.

The same rules for finding wind direction apply as with the "Calculator."

BRITISH PILOT-BALLOON METHODS: THE SHOEBURYNESS SYSTEM.

[Reprinted from Meteorological Office Circular 30, Nov. 26, 1918, pp. 1-2.]

The following is a description of the double-theodolite method in use at Shoeburyness: The method is a combination of graphical and slide-rule methods. On a large drawing board there are fixed two of the radial charts supplied by the Meteorological Office, joined so as to have lines radiating to the left as well as to the right. The common center of these charts represents the home station. A paper protractor (obtained by cutting up a radial chart) is arranged so that its center is at a distance from the center of the radial charts equal to the length of the base between the theodolite stations on a scale of 2 cm. to 600 feet; the bearing of the center of the protractor is the bearing of the distant, from the home, station. The whole is covered with a sheet of tracing paper on which the path of the balloon is plotted. The tracing paper is renewed when necessary, but the radial charts seldom require renewal. Two Chesterman steel tapes are pivoted one at the center of the radial chart and the other at the center of the protractor. The home theodolite is set with azimuth N.=180° and the distant theodolite with zero—bearing of the home station. The steel tapes are set according to the simultaneous readings of the azimuth of the balloon, and their intersection on the plotting tables gives the projection of the balloon. Successive positions at intervals of one minute are plotted in this way. The wind speed is obtained directly in feet per second by measuring the distances between successive points. As the scale is 2 cm. to 600 feet the speed in feet per second is measured on the scale of 2 cm. to 10 f./s. The wind-direction is obtained by setting a rolling parallel ruler along the line joining two successive points; the ruler is then rolled until it coincides with one of the lines of the radial charts. This gives the wind-direction directly. The distances from the intersections on the charts to the origins are read off on the steel tapes, 2 cm. being taken as the unit. These give HcotE/600 for each station where H is the height in feet above the station from which the elevation of the balloon is E. From this the height above each station is computed by slide-rule. A pilot balloon slide-rule is used: 1 on the inner slide is set against 6 on the main slide. The tangent cursor is set to the complement of the angle of elevation and the inner slide is then set so that the horizontal distance of the balloon from either station, as measured on the plotting board, falls under the cursor. Height in feet is then read against the end of the sine-scale.

The ends of the base and the office where the computing is done are connected by telephone. The telephone installation is arranged so that any observer who is using the telephone can speak to and hear either of the other two. This is the case whichever base is being used. Five observers are required; they are allocated as follows: